Test of leptonic universality in J/ψ decays

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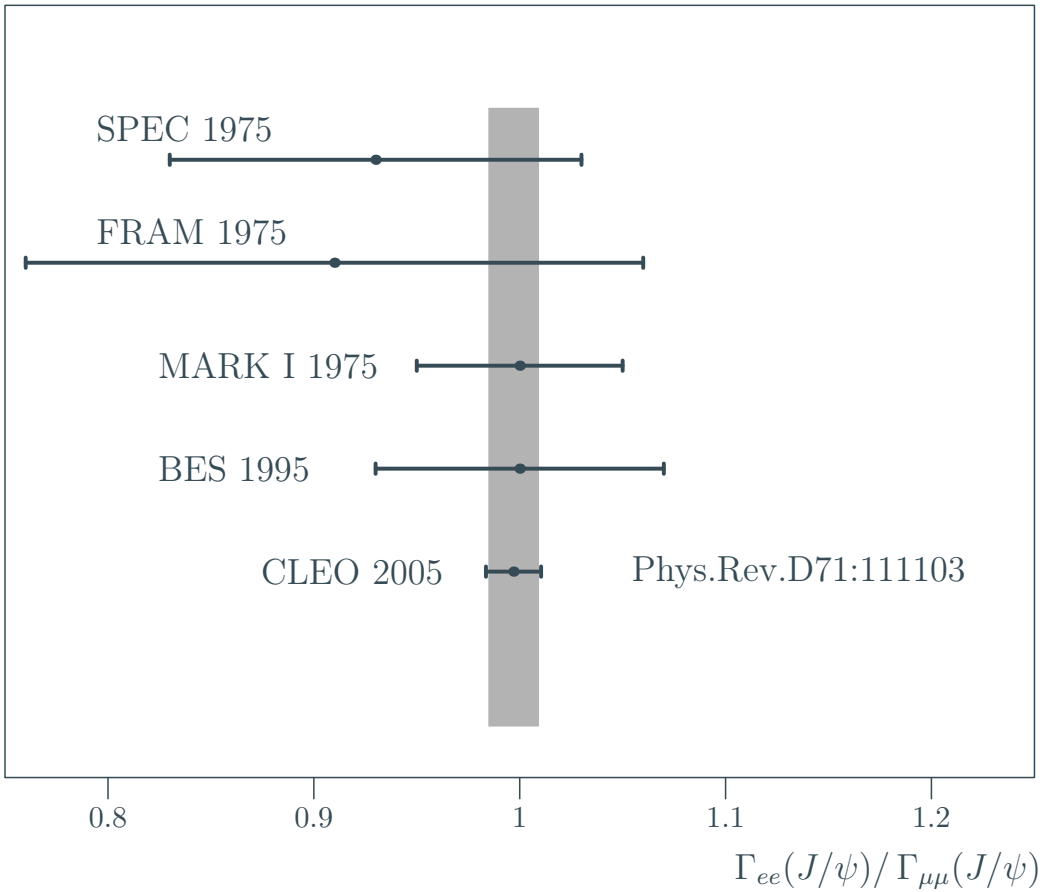
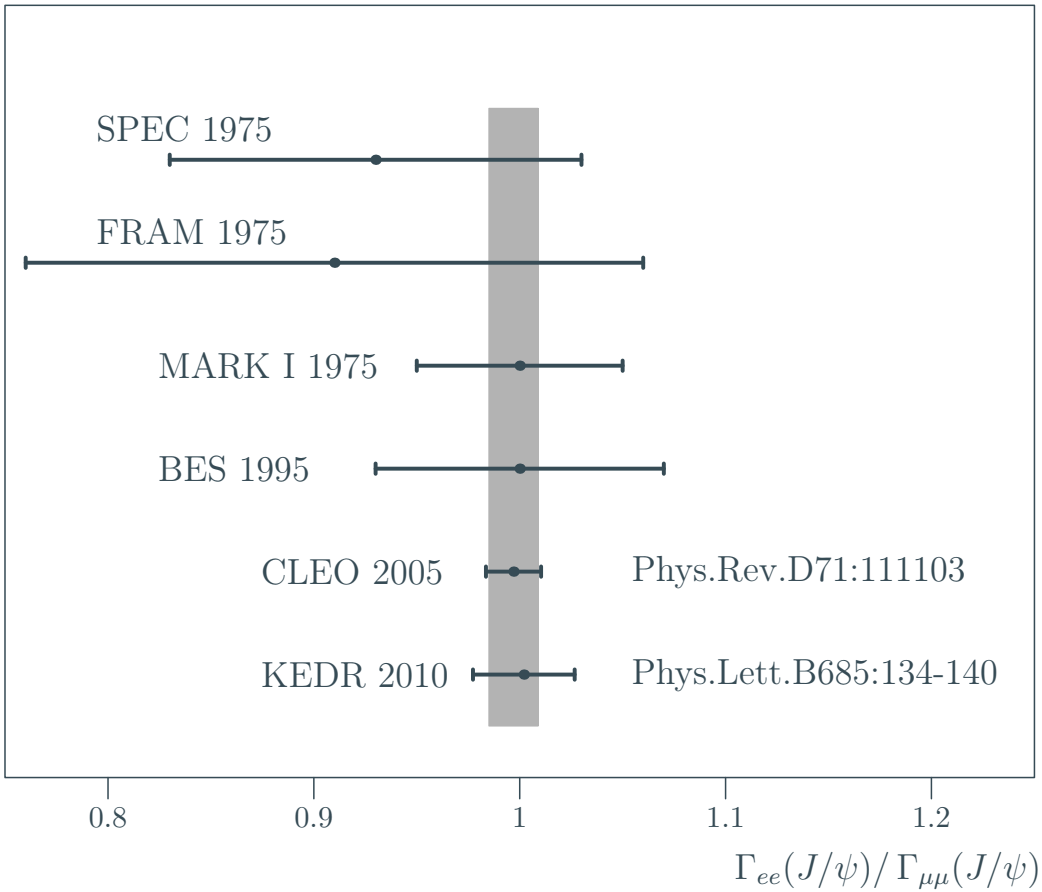
Outline

Recent history of $\Gamma_{ee}/\Gamma_{\mu\mu}$ measurement



CLEO $\mathcal{B}_{ee}/\mathcal{B}_{\mu\mu} = 0.997 \pm 0.012 \pm 0.006$ (1.3%) using $\psi(2s)$

Recent history of $\Gamma_{ee}/\Gamma_{\mu\mu}$ measurement



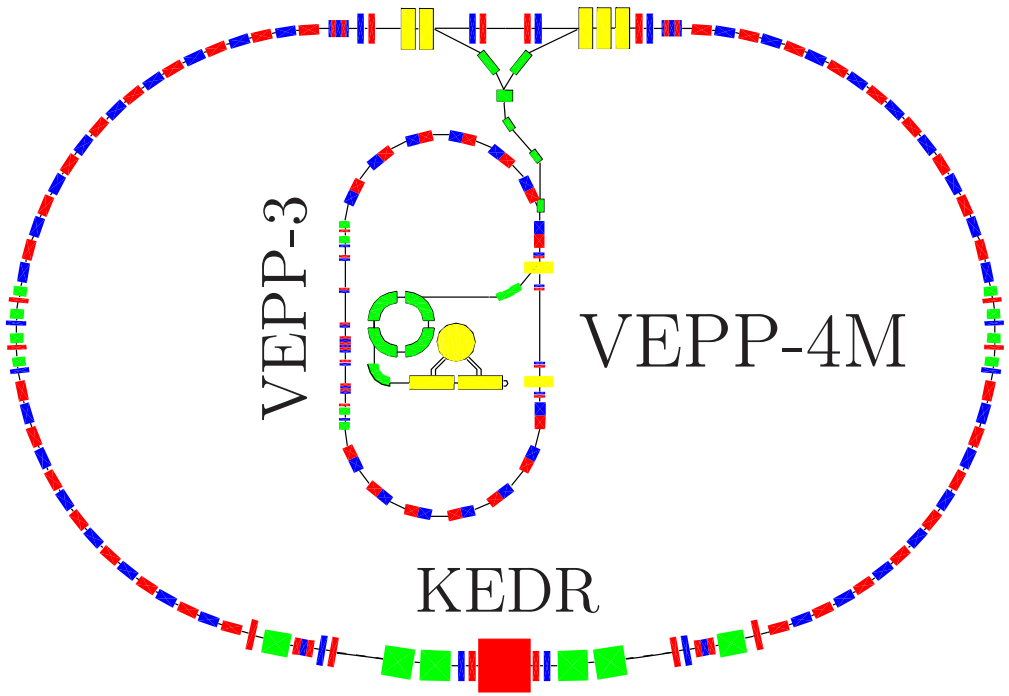
CLEO $\mathcal{B}_{ee}/\mathcal{B}_{\mu\mu} = 0.997 \pm 0.012 \pm 0.006$ (1.3%) using $\psi(2s)$

KEDR $\Gamma_{ee}/\Gamma_{\mu\mu} = 1.002 \pm 0.021 \pm 0.013$ (2.5%)

$\Gamma_{ee} \times \Gamma_{ee}/\Gamma = 0.3323 \pm 0.0064 \pm 0.0048$ keV (2.4%)

$\Gamma_{ee} \times \Gamma_{\mu\mu}/\Gamma = 0.3318 \pm 0.0052 \pm 0.0063$ keV (2.4%)

VEPP-4M collider

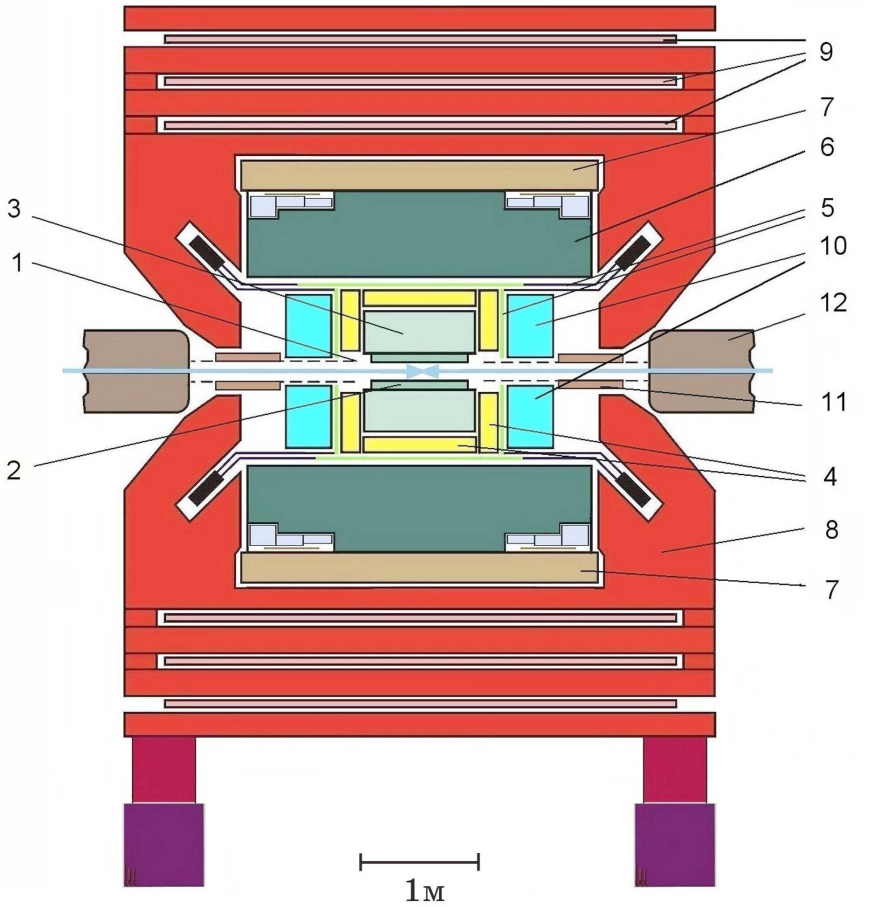


- Beam energy $1 \div 6$ GeV
- Number of bunches 2×2
- For $E = 1.5$ GeV
  - Beam current 1.5 mA
  - Luminosity $10^{30} \frac{1}{\text{cm}^2 \cdot \text{c}}$

Beam energy measurement:

- Resonant depolarization technique:
  Instant measurement accuracy $\simeq 1 \times 10^{-6}$
  Energy interpolation accuracy $(5 \div 15) \times 10^{-6}$ $(10 \div 30$ keV$)$
- Infra-red light Compton backscattering:
  Statistical accuracy $\simeq 5 \times 10^{-5}$ / 30 minutes
  Systematic uncertainty $\simeq 3 \times 10^{-5}$ $(50 \div 70$ keV$)$

KEDR



1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. Threshold aerogel counters
5. ToF counters
6. Liquid krypton calorimeter
7. Superconducting coil
8. Magnet yoke
9. Muon tubes
10. CsI-calorimeter
11. Compensation solenoid
12. VEPP–4M quadrupole

Cross section

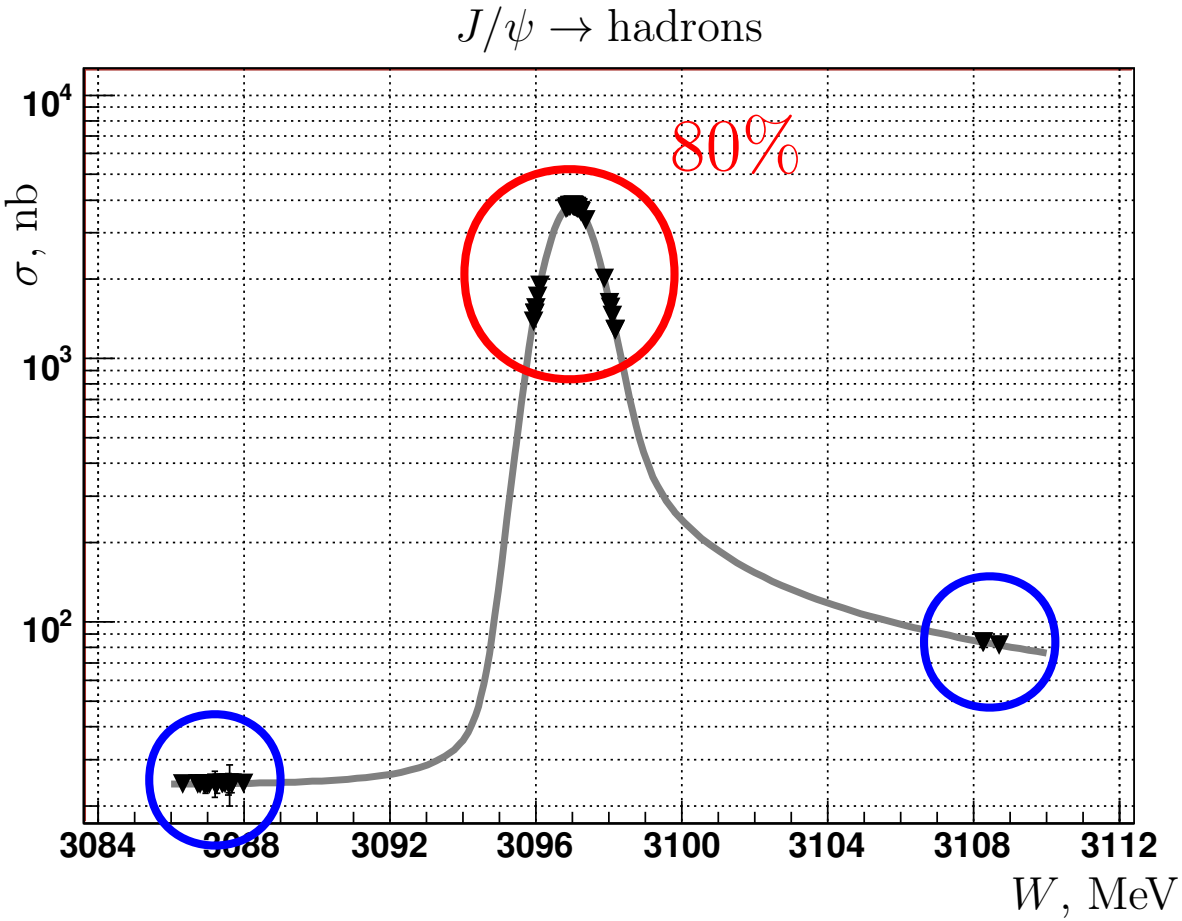
$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee} = \frac{1}{M^2}(1+\delta_{\rm rc})\left\{\frac{9}{4}\frac{\Gamma^2_{e^+e^-}}{\Gamma M}\left(1+\cos^2\theta\right)\mathrm{Im}\,\mathcal{F} - \right.$$
$$\left. - \frac{3\alpha}{2}\frac{\Gamma_{e^+e^-}}{M}\left[(1+\cos^2\theta) - \frac{(1+\cos\theta)^2}{(1-\cos\theta)}\right]\mathrm{Re}\,\mathcal{F}\right\} + \left(\frac{d\sigma}{d\Omega}\right)^{ee\to ee}_{\rm QED}$$

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu} = \frac{1}{M^2}(1+\delta_{\rm rc})\left\{\frac{9}{4}\frac{\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}}{\Gamma M}\mathrm{Im}\,\mathcal{F} - \right.$$
$$\left. - \frac{3\alpha}{2}\frac{\sqrt{\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}}}{M}\mathrm{Re}\,\mathcal{F}\right\}\left(1+\cos^2\theta\right) + \left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu}_{\rm QED}$$

where $\mathcal{F} = \left(\frac{\frac{M}{2}}{-W+M-\frac{i\Gamma}{2}}\right)^{1-\beta}$, $\beta = \frac{4\alpha}{\pi}\left(\ln\frac{W}{m_e} - \frac{1}{2}\right) \simeq 0.077$

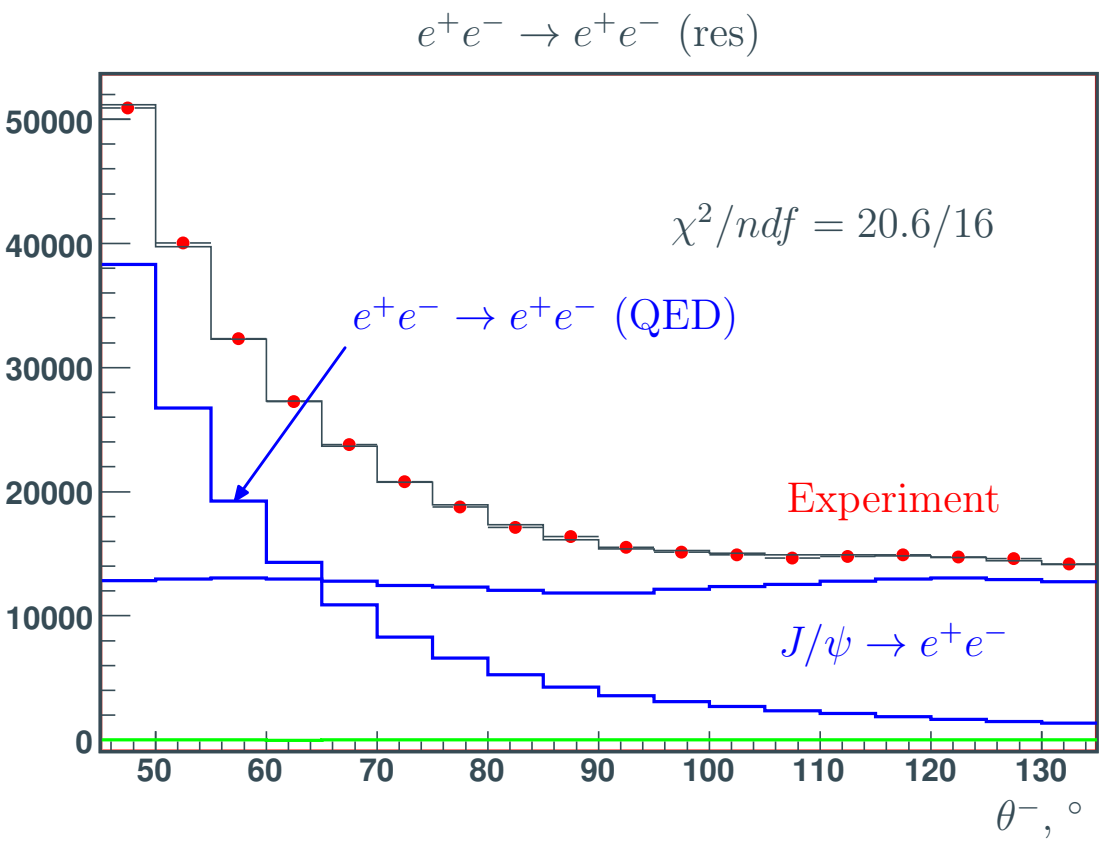
Corrections to the vacuum polarization are omitted in the interference terms.

Experiment



The integrated luminosity of 2.1 pb^{-1} was collected in Dec 2007 – Jan 2009

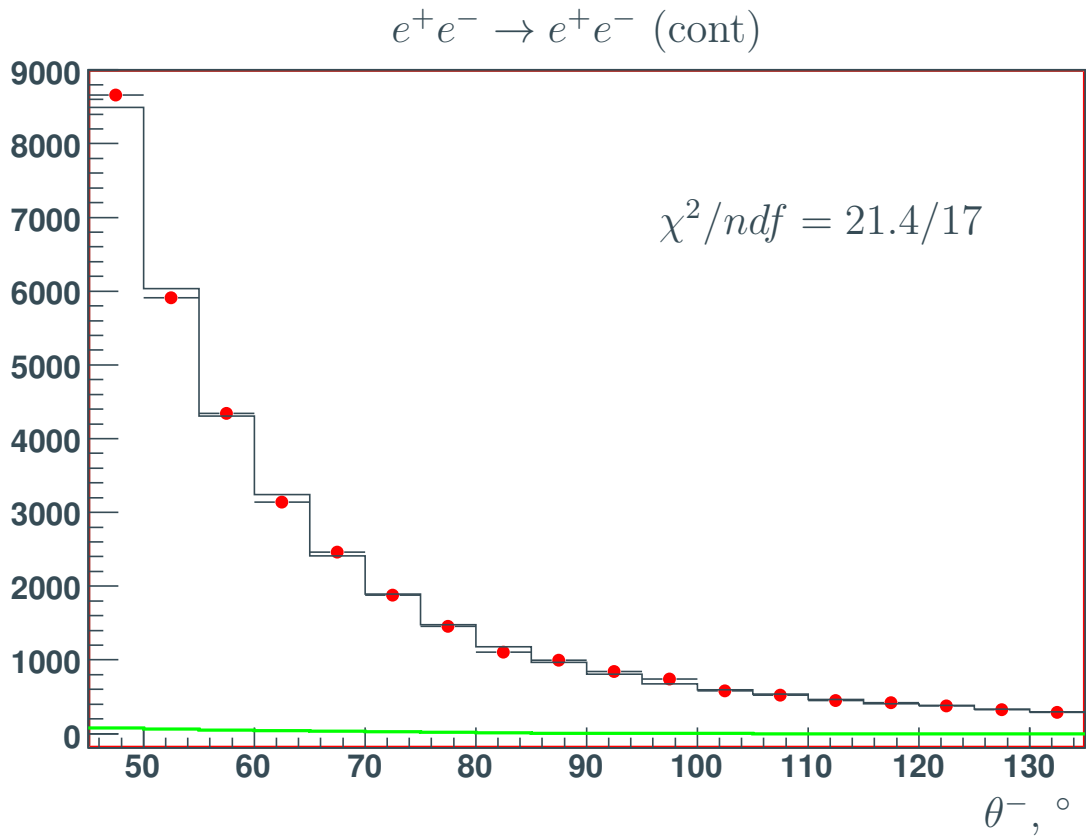
$J/\psi \to e^+e^-$ (resonance) counting



$$\frac{dN_{ee}^{\text{obs}}}{d\theta} = aN_0^{\text{sim}}\left(\text{Res}(\theta) + \frac{2\alpha}{3\mathcal{B}_{ee}}\langle F_{\text{res}}(E)\rangle\,\text{Int}(\theta)\right) + L_{\text{res}}\left(\frac{d\sigma}{d\theta}\right)_{\text{QED}}$$

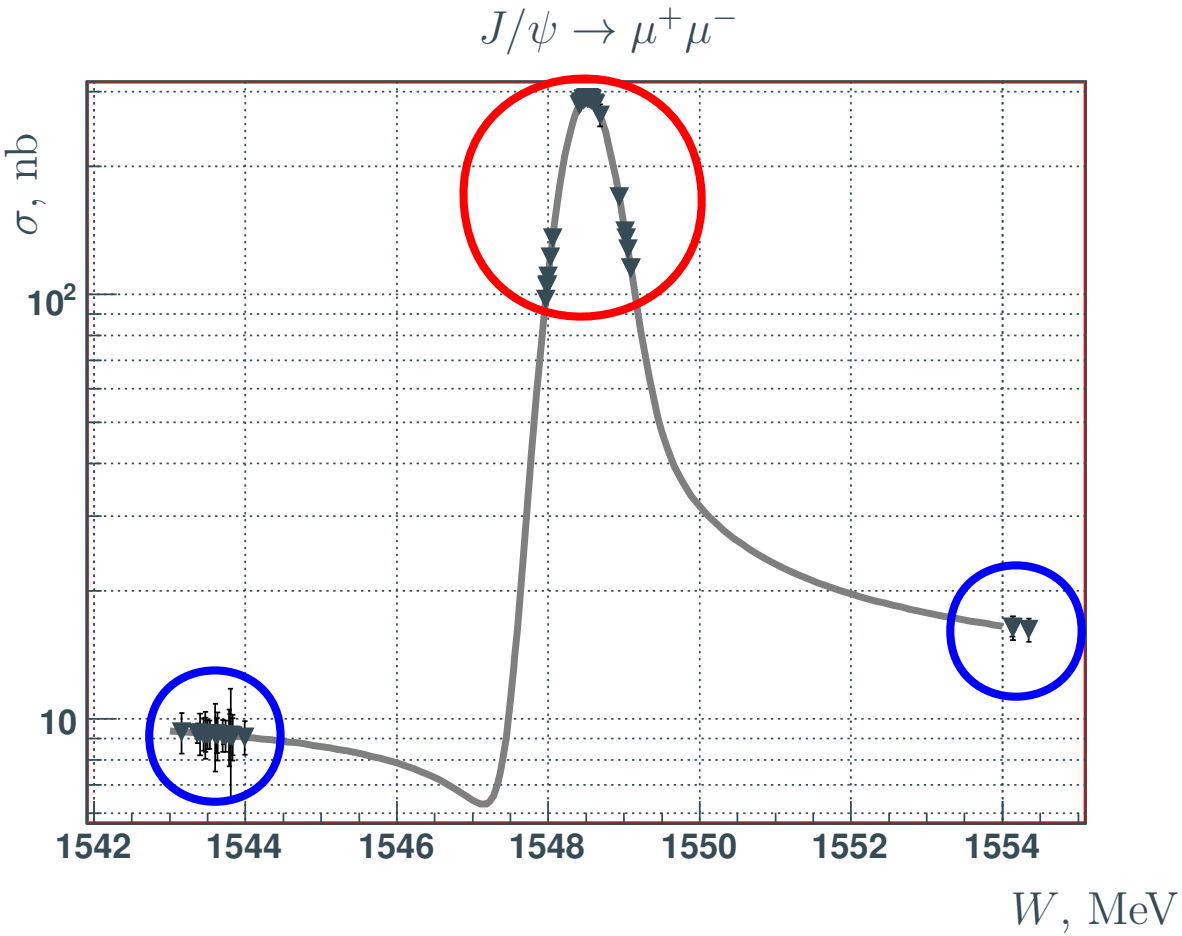
$$N_{J/\psi\to ee} = \frac{aN_0^{\text{sim}}}{\varepsilon_{J/\psi\to ee}},\quad \frac{\delta N_{J/\psi\to ee}}{N_{J/\psi\to ee}} = 0.33\%$$

$e^+e^- \to e^+e^-$ (continuum)



$$\frac{dN_{ee}^{\text{obs}}}{d\theta} = L_{\text{cont}} \left\{ \langle b(E) \rangle \, N_0^{\text{sim}} \left(\text{Res}(\theta) + \frac{2\alpha}{3\mathcal{B}_{ee}} \langle F_{\text{cont}}(E) \, \text{Int}(\theta) \right) + \left(\frac{d\sigma}{d\theta} \right)_{\text{QED}} \right\}$$

$J/\psi \to \mu^+\mu^-$ counting

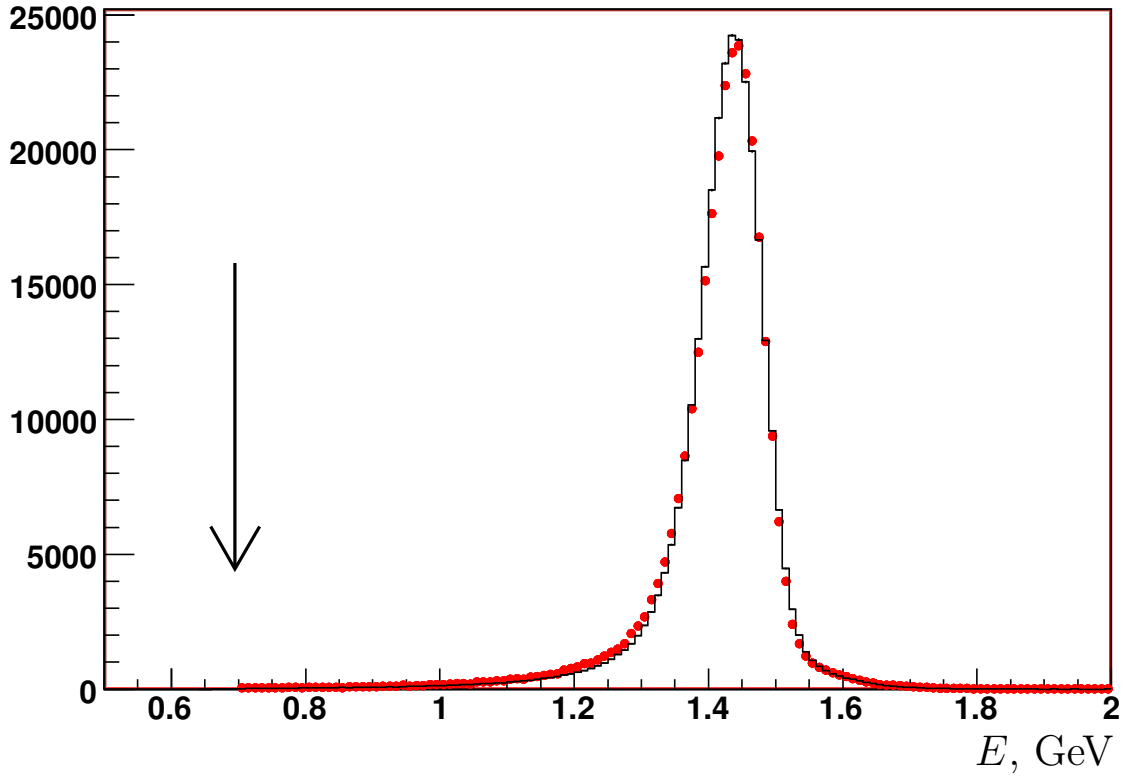


$$N_{J/\psi\to\mu\mu} = \frac{\left\{ N^{\text{exp}}_{\text{res}} - N^{\text{th}}_{\text{int}} - \frac{L_{\text{res}}}{L_{\text{cont}}} \times \left(N^{\text{exp}}_{\text{cont}} - N^{\text{th}}_{\text{int}} \right) \right\}}{\varepsilon_{J/\psi\to\mu\mu}}, \quad \frac{\delta N_{\mu\mu}}{N_{\mu\mu}} = 0.29\%$$

Event selection

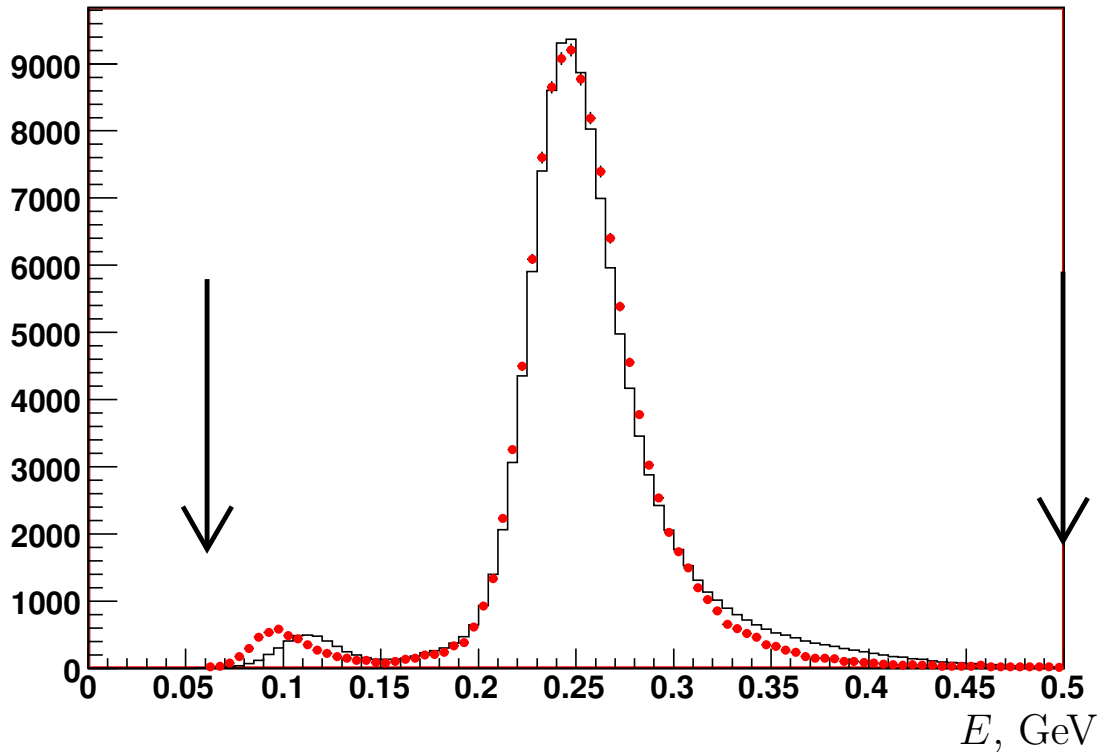
1. 2 charged tracks with opposite signs from a common vertex in the interaction region,
2. $E_{\text{all}} - (E_+ + E_-) < 0.15\,\text{GeV}$,
3. θ and φ acollinearity $< 10^\circ$,
4. $p_\pm > 0.5\,\text{GeV}$,

e^+e^- selection



5. $E_{\pm} > 0.7$ GeV
6. $\theta^- \in 41 \div 139°$, $\theta^+ \in 38 \div 142°$

$\mu^+\mu^-$ selection



5. $0.06\,\text{GeV} < E_{\pm} < 0.5\,\text{GeV}$
6. $\theta^- \in 49 \div 131°$, $\theta^+ \in 46 \div 134°$
7. $| t^{\pm} \times \sin(\theta^{\pm}) - t_{90°} | < 3 \times \sigma_t$, where $t_{90°} = 2.40\,\text{ns}$, $\sigma_t = 0.36\,\text{ns}$
8. continuation in the muon system for μ^-

Simulation

- $e^+e^- \to e^+e^-(\gamma)$
  - Resonance contribution $\frac{d\sigma}{d\Omega} \propto (1+\cos^2\theta)$ + PHOTOS
  - Interference terms with the angular distributions $(1+\cos^2\theta)$ and $(1+\cos^2\theta)^2/(1-\cos\theta)$ + PHOTOS
  - $d\sigma_{\mathrm{QED}}/d\theta$ (Bhabha) BHWIDE and MCGPJ
- $e^+e^- \to \mu^+\mu^-(\gamma)$
  - Resonance contribution $\frac{d\sigma}{d\Omega} \propto \beta \times \left(1+\cos^2\theta + \left(1-\beta^2\right) \times \sin^2\theta\right)$ + PHOTOS
  - Interference term $\frac{d\sigma}{d\Omega} \propto (1+\cos^2\theta)$ + PHOTOS
- Background
  - $J/\psi \to$ hadrons BES generator
  - $e^+e^- \to \gamma\gamma$ BABAYAGA

Experimental data recorded with "random trigger" are added to simulated events to account for pile up effect.

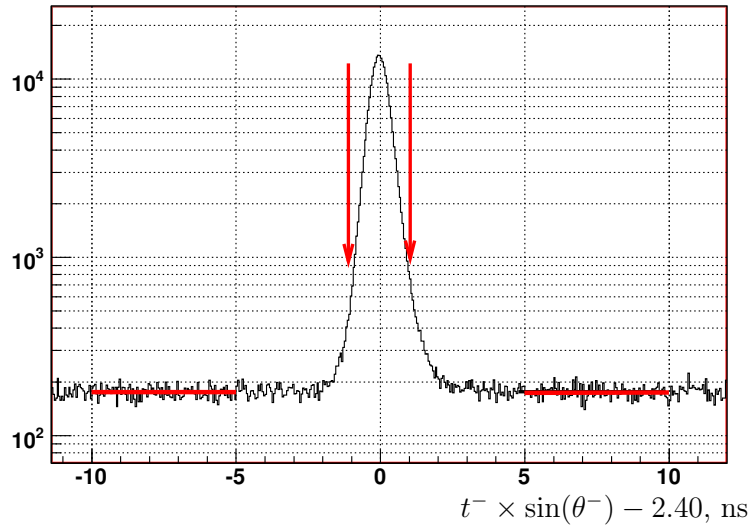
Systematic uncertainty (1)

Source	Contribution, %	Error, %
Interference		
Relative luminosity		0.01
Energy measurement		0.02
Radiation corrections		0.10
Background		
$J/\psi \to$ hadrons	-0.05	0.10
$e^+e^- \to \gamma\gamma$	-0.07	
Cosmic		0.07
Simulation		
Bhabha		0.11
PHOTOS	$+0.20$	0.02
to be continued		

Systematic uncertainty (2)

Source	Correction, %	Error, %
Trigger		
1st level	-0.70	0.20
2nd level	-1.17	0.11
Event selection		
tracking system	$+1.18$	0.10
calorimeter	$+0.27$	0.10
muon system	-0.12	0.04
θ angle cuts		0.10
θ angle determination		0.14
Selection asymmetry		0.14
ToF inefficiency	-22.3	0.26
Total		0.48

ToF inefficiency



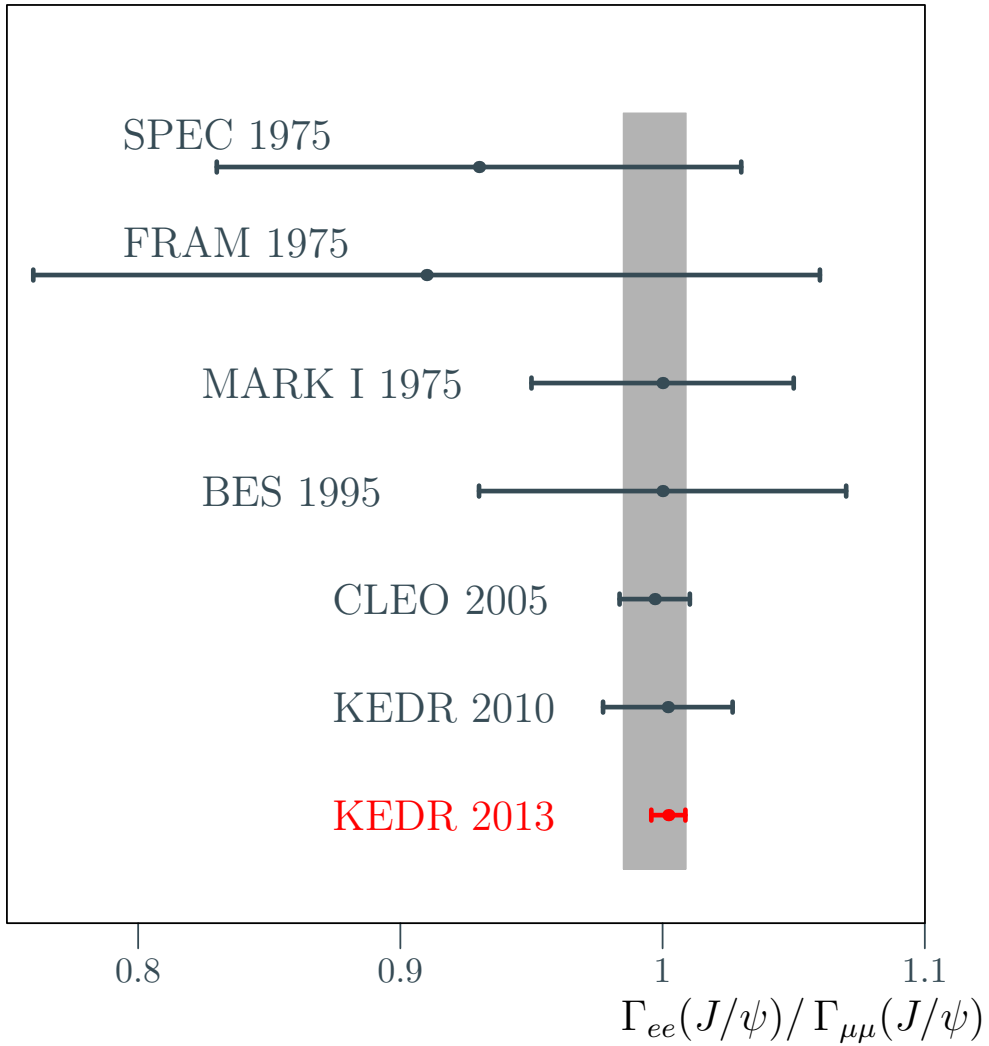
$$\varepsilon_{\text{ToF}}^{\mu\mu} = \varepsilon_{\mu^+}(\text{with } \mu^- \text{ time cut}) \times \varepsilon_{\mu^-}(\text{with } \mu^+ \text{ time cut}) = (77.78 \pm 0.12 \pm 0.03)\%$$

Check for possible correlation of $\varepsilon_{\mu^+(\mu^-)}$, $\varepsilon_{\mu^-(\mu^+)}$:

$$\begin{cases} \varepsilon_{\text{ToF real}}^{ee} = 76.35\% \\ \varepsilon_{e^+(e^-)} \times \varepsilon_{e^-(e^+)} = 76.51\% \end{cases} \Rightarrow \frac{\delta\varepsilon_{\text{ToF}}}{\varepsilon_{\text{ToF}}} = 0.21\%$$

▸ Systematic uncertainty

Comparison



$$\Gamma_{e^+e^-}(J/\psi)/\Gamma_{\mu^+\mu^-}(J/\psi) = 1.0022 \pm 0.0044 \pm 0.0048 \ (0.65\%)$$

Preliminary

Theory (misc)

The formulae used in this analysis are based on the analitical expression of radiative correction intergal in the soft photon approximation (SPA) first obtained in Y. I. Azimov *et al.*, JETP Lett. **21** (1975) 172.

The accuracy improved using E. A. Kuraev and V. S. Fadin, Sov. J. Nucl. Phys. **41** (1985) 466. as described in V. V. Anashin *et al.*, Phys. Lett. B **711** (2012) 280

In the SPA the formulae are equivalent to that of R. N. Cahn Phys. Rev. D **36** (1987) 2666 corrections beyond SPA are not essential for this analysis.

▸ Cross section

$$\delta_{\mathrm{rc}} = 1 + \frac{3}{4}\beta + \frac{\alpha}{\pi}\left(\frac{\pi^2}{3} - \frac{1}{2}\right) + \beta^2\left(\frac{37}{96} - \frac{\pi^2}{12} - \frac{L}{72}\right),$$

where $L = \ln(W^2/m_e^2)$.

[Kuraev and Fadin, Sov. J. Nucl. Phys. 41, 466–472, 1985]

▸ Cross section

$J/\psi \to e^+e^-$ (resonance) counting (misc)

$$\langle F(E)\rangle = \frac{\sum L_i^{1\gamma} \mathrm{Re}\, \mathcal{F}(E_i)}{\sum L_j^{1\gamma} \mathrm{Im}\, \mathcal{F}(E_j)} \times \left(1 - \frac{\int \frac{(1+\cos\theta)^2}{(1-\cos\theta)}\, d(\cos\theta)}{\int 1+\cos^2\theta\; d(\cos\theta)}\right),$$

$$\langle b(E)\rangle = \frac{\sum L_i^{1\gamma} \mathrm{Im}\, \mathcal{F}(E_i)}{\sum L_j^{1\gamma}},$$

where $L_{1\gamma}$ — integrated luminosity by single bremsstrahlung.

▸ $J/\psi \to e^+e^-$ event counting

▸ $e^+e^- \to e^+e^-$ (continuum)